These results also accord with the appearance of the plants themselves. The want of P_2O_5 results in a long limp growth, and very pale colour, and the attacked spots show corrosion and collapse instead of normal flecks.

Similarly, in plants deprived of K we have pale collapsing patches in place of normal flecks, though the plant is not drawn and etiolated as in the previous case. Where Mg was wanting the drawing and paleness of the leaves were not so marked, and the fungus flecks in the positive case were more like the normal.

That a want of supplied Ca should have very little effect on either host or parasite, was no doubt due to there being small quantities available in the soil and pots. The flecks and pustules were apparently normal, though small.

It is not easy to see why the pots with water only yielded plants with flecks as good as, or even better than those with normal solution, unless the concentration of the salts affects the fungus. However it is probably not to be inferred that in any of these cultures the grass was totally deprived of the given salt—it would get traces from the pots and coir in any case—but the effects of deprivation of salts ought certainly to be felt, and I think were so to some extent in lengthening the incubation period.

So far as the results go they suggest that differences in the supply of minerals affects the development of mycelium and of spores owing to effect on the host—in cultivating the host we also cultivate the parasite.

But I would insist that these trials with special mineral-supplies are merely preliminary. The task in hand was far too extensive for the problems to be solved in one season, and I contemplate carrying the whole matter—or persuading some one to do so—much farther in the future. Meanwhile, the results give suggestions for further work, and much remains to be done along the lines I have here laid down, as well as in directions yet to be opened out.

"On the Physics and Physiology of the Protoplasmic Streaming in Plants." By ALFRED J. EWART, B.Sc. (Oxon.), D.Sc. (Lond.), Ph.D., F.L.S., Lecturer on Botany in the Birmingham Technical Institute. Communicated by FRANCIS GOTCH, D.Sc., F.R.S. Received January 17,—Read February 20, 1902.

(Abstract.)

The results of an extended series of observations upon this phenomenon have led the author to conclusions which may be summarised as follows:—

The energy of movement is generated in the moving layers themselves, and these are retarded by friction against the non-moving ectoplasm to an extent determined by their own viscosity, and to a much less extent by friction against the cell-sap which is passively carried with the stream. The motor-mechanism is such that no backward reaction is exercised upon the external or internal layers. The velocity of streaming is largely dependent upon the viscosity of the protoplasm, and hence also upon the percentage of water in the latter, but the osmotic pressure exercises little or no direct influence upon streaming.

The activity of diosmosis is not necessarily increased by the existence of streaming, but secondarily induced differences of osmotic pressure may be perceptible between streaming and quiescent cells.

Albuminous solutions containing 89—90 per cent. of water have at 18—20° C. a viscosity of from 0·06 to 0·07, with 95 per cent. of water 0·04, with 72 per cent. 0·29 C.G S. unit.

Gravity exercises little or no influence upon streaming in small cells, and only a very slight indirect action on streaming in large ones. The velocity of floating particles of greater or less density than the plasma may be distinctly affected by gravity, a fact which indicates that the viscosity of the streaming plasma is comparatively low.

As the temperature rises within certain limits (0° C. to 45 or 50° C.), the viscosity of the plasma decreases, and a large part of the increased velocity is due to this cause alone.

Assuming that the viscosity of the endoplasm corresponds approximately to that of 10 per cent. albumin, forces of 8·75 and 219 dynes would be required to impart velocities of 2 mm. and 0·4 mm. per minute to a gramme of moving liquid in cells of 0·1 and 0·01 cm. internal diameter. The amount of work done in a year represents, in the first case, a theoretical consumption of only $\frac{1}{20000}$th of a gramme of cane-sugar per gramme of moving liquid, and in the second represents only $\frac{1}{1000}$th of the energy of respiration, even if 99 per cent. of the energy directed towards streaming is wasted. The force required varies inversely as the square of the radius, so that in a 50-cm. tube of the cribral system of *Cucurbita*, having 2000 sieve-plates with sieve-pores of 2 μ diameter and 10 μ length, a pressure of approximately half an atmosphere would be required to produce a movement in mass of the contents through the tube at a rate of 0·5 mm. per minute. Hence an internal pressure of 5 atmospheres would cause an escape of the contents of an opened sieve-tube at an average rate of about 5 mm. per minute, so long as the pores remained unblocked, which corresponds with the slow exudation taking place when a moderately turgid sieve-tube is first opened.

Regular protoplasmic streaming does not seem to occur even in the individual segments of sieve-tubes, and hence there is no need to discuss whether the protoplasm could generate the propulsive force

required to produce moderately rapid streaming through the pores. The differences of hydrostatic pressure between the different segments of an intact sieve-tube would, however, frequently suffice to produce a direct transference in mass of the fluid contents through the pores of sieve-tubes at a millimetre or so per minute,* for, as evidenced by the influence of gravity and of centrifugal force upon suspended particles, the viscosity of the contents of the sieve-tubes is relatively low.

In the case of bacterium cells of 2 to 0·5 μ diameter, it is very doubtful whether the protoplasm could with economy generate the required propulsive force for perceptible internal streaming movements. The latter take place in diatoms mainly on the external surface, and require relatively little expenditure of energy.

In the case of protoplasmic threads passing through fixed channels in the cell-wall, if these are $\frac{1}{10}\,\mu$ diameter and 5 μ length, a pressure of over 6 atmospheres would be required to drive a liquid of viscosity 0·075 through a single thread at a velocity of 1 mm. per second. So that if a tissue-cell were isolated, it would at the lowest computation take several years for the escape of 1 cubic mm. of the cell-contents through one such thread under a maximal internal osmotic pressure, even supposing that the thread did not become plugged by floating particles and that no cellulose was formed across its exposed end. The outer layers of the ectoplasm appear, moreover, to be very much more viscous than the endoplasm, and hence it is obvious that the threads do not subserve purposes of translocation, although minute particles of protoplasm may be bodily transferred from one cell to another in the course of time.

The direction of streaming is mainly determined by internal factors, and in rotating cells a reversal is only possible in certain cases and under very special conditions.

Changes occur spontaneously however in cells exhibiting circulation. The total resistance during circulation is greater than during rotation, and hence, unless the velocity increases considerably, a change from the former to the latter after stimulation is not due to an increased energy of streaming but to a change in the configuration of the protoplasm.

The energy for streaming can be derived either from aerobic or anaerobic metabolism. Certain species of *Chara* and *Nitella* are in fact facultative anaerobes, and may exhibit slow streaming for 6—8 weeks in the entire absence of free oxygen.

No special chemical changes are connected with streaming.

* According to de Bary ('Compt. Anat.,' 1884, p. 177) finger-like processes from the adjoining segments of a sieve-tube meet in the sieve-pores, but remain distinct. This discontinuity has only been observed in dead sieve-tubes, and it probably results from the breaking of the viscous protoplasmic threads at their thinnest points on death, which is a surface-tension effect commonly produced in dying protoplasmic threads.

Of the different constituents of the cell, cellulose, albumin, and chlorophyll are paramagnetic; starch, sugar, oil, water, and probably myosin also, are diamagnetic. Plant-cells usually, though not always, place their long axes parallel to the lines of force in a magnetic field.

The strongest magnetic field used exercised little or no direct effect on streaming, although a pronounced secondary effect is produced on prolonged exposure as the result of inductive action.

The connection between certain forms of streaming movement, such as occur in a few fungi, and metabolism is a wholly indirect one, but this can hardly be a general rule. Indirect relationships exist between streaming, growth, and assimilation, but no direct ones. Similarly the nucleus exercises no direct but a pronounced indirect influence on streaming.

An organised arrangement of the emulsionised protoplasmic particles is probably an essential condition for regular continuous streaming. A great variety of agencies when suddenly applied seem to disturb this arrangement momentarily, and hence produce a temporary cessation of streaming. This shock-effect results from sudden changes of concentration, sudden falls or rises of temperature, momentary electrical excitation, and the sudden application of various poisons.

The minimal, optimal, and maximal temperatures for streaming vary according to the plant or cell examined, and also depend upon (1) the age or condition, (2) the external medium, (3) the duration of the exposure, (4) the supply of oxygen, (5) the rapidity with which the temperature is raised or lowered.

At temperatures above 30° C. the velocity immediately assumed is, in the absence of a shock-effect, always greater than that shown a few hours or a few minutes afterwards. Between 10° and 30° C. the permanent velocity is almost immediately assumed. Below 10° C. the acceleration due to a rise of temperature frequently does not become fully manifest until after a certain lapse of time.

In the case of facultative anaerobes, the response to changes of temperature is less pronounced in the absence of oxygen than in its presence. With short exposures the optimum and maximum points are raised, but with prolonged ones the maximum temperature is lowered by the absence of oxygen.

Strong light retards streaming, while weak light may indirectly accelerate it in chlorophyllous cells. It is still doubtful whether streaming is affected by directly impinging electro-magnetic wave-vibrations other than those of light.

Mechanical disturbances may act as inhibitory stimuli, and may be propagated internally in the form of pressure-waves.

Food-materials exercise both a direct and an indirect effect upon streaming. Acids, alkalies, and metallic poisons all retard streaming, and may cause a temporary shock-stoppage when suddenly applied.

Alcohols and anæsthetics when dilute may accelerate streaming, but when more concentrated always retard it. Alkaloids, which are strong nerve or muscle poisons, have relatively little action upon the streaming protoplasm of plants.

Weak electrical currents may accelerate streaming, strong ones always retard it, while sudden shocks produce a temporary cessation. The latent period of recovery decreases as the temperature rises up to the optimum. Weak constant currents lower the optimal and maximal temperatures for streaming. Cells are more sensitive to electrical stimuli at moderately high temperatures than at very low or very high ones, and the nucleus is fatally affected before the cytoplasm.

The electrical conductivity of the protoplasm undergoes a slight temporary increase on death, and it differs in the living cell from that of the cell-sap and of the cell-wall. The effect produced by a weak constant current bears no relation to its direction with regard to the plane of streaming.

There is little or no analogy between a shock-stoppage of streaming and a muscular contraction, or between a nerve-muscle preparation and a streaming cell. No permanently differentiated nervous mechanism exists in plants, although temporary better-conducting channels may appear as the result of prolonged stimulation or at certain stages in the development of growing organs. Excitatory changes may be transmitted in the protoplasm of a cell of *Chara* or *Nitella* at from 1 to 8 or 20 mm. per second (18° C.), but the rate of propagation from cell to cell in tissues varies from 0·1 to 2 mm. per minute at 18° C. Neither the chloroplastids nor any of the visible floating particles in the protoplasm have any power of independent movement, but are passively carried with the moving stream.

The only kind of energy which appears capable of producing streaming movements under the conditions existing in plant-cells is surface-tension energy, and this is probably brought into play by the action of electrical currents which traverse the moving layers, and are maintained by chemical action in the substance of the protoplasm. These currents may act upon more or less regularly arranged bipolar particles of emulsionised protoplasm in such a manner as to reduce their surface-tension on the anterior side, or increase it on the posterior one, hence producing streaming movement in a definite direction.